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Biofuels and fossil fuels: Life Cycle Analysis (LCA) optimisation through productive resources maximisation

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ABSTRACT

Life Cycle Analyses (LCA) are used to compare biofuels to fossil fuels. These analyses are made according to the ISO 14040-43 standards, which using a defined unit compare mass and energy balances for two or more comparison objects.

In Spain, the Spanish government Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas, CIEMAT, has performed two LCA's in order to compare ethanol and ethanol mixtures with unleaded gasoline and biodiesel and biodiesel mixtures with fuel-oil according to these standards. Both LCA's conclude that biofuels require less primary energy than fossil fuels to be processed and that CO_2 emissions are lower when using biofuels instead of fossil fuels.

However, these LCA's have been strongly criticized for several reasons. This report presents a new LCA model which allows the comparison of biofuels and fossil fuels based on the maximisation and optimisation of production resources avoiding the disadvantages of the traditional LCA model based on the ISO 14040-43 standards.

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1. Introduction

1.1. Reasons to perform a Life Cycle Analysis (LCA)

At present we live in an age where "sustainability" is more appreciated than other trends such as quality, speed and production flexibility which dominated the last quarter-century. This new sustainability era is motivated primarily by social awareness in achieving a balance between human development and conservation of the environment. "Sustainability" and in turn "sustainable development" are concepts that mean different things to different people, making it impossible to provide a single definition. The original definition of sustainable development (and the one still most widely used) was made in the Bruntland Report [1], (Our Common Future, World Commission on Environment and Development in 1987) which defined it as:

> "Development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs".

In other words, sustainable development seeks to ensure a better quality of life for all both now and in the future. Nowadays, the automotive fuel market is almost 100% dominated by fossil fuels. Oil is finite and will not last forever. Hence, its use is not considered as "sustainable" because future generations' development may be compromised due to its consumption. For this reason, alternative fuels to fossil fuels have been searched for decades and one of these alternatives is the use of biofuels.

At this point the question that arises is to know if biofuels are good substitutes for fossil fuels. In order to answer it, LCA's of biofuels and fossil fuels have to be performed in order to compare their advantages and disadvantages.

1.2. LCA description

LCA's are covered by ISO 14040-43 standards. In other words, an LCA consists of the following phases:

1. Definition of objectives.
2. Election of the systems to be studied.
3. Functional unit definition.
4. Definition of systems to be compared.
5. Identification of systems' limits.
6. Comparison of results.

Thus, LCA's consist of two "balances" (evaluations) to compare biofuels and fossil fuels:

- "Mass balance", i.e., quantify and evaluate the income and outcome products within the life cycle of a fuel.
- "Energy balance", i.e., evaluate income and outcome energy (heat and work produced or required) within the life cycle of a fuel.

2. CIEMAT's Life Cycle Analysis for biofuels and fossil fuels

2.1. Description

CIEMAT has developed two life-cycle analysis of biofuels for Otto cycle engines [2] and Diesel cycle [3] according to the ISO 14040-43 standards.

2.2. Objectives

The objectives of the studies carried out by CIEMAT are the following:

- To evaluate and quantify the environmental impacts for two fuels for the same purpose along their entire life cycle.
- To compare their associated impacts.
- To identify and evaluate the opportunities to minimise these impacts once they have been identified in each phase of the process.
- To analyse the environmental benefits of the different fuels.

2.3. Election of the systems to be studied

2.3.1. Note regarding the reference systems

Biofuel production generates by-products and it is considered that these by-products replace existing products that already exist in the market. Hence, the production processes of the existing products are to be considered within the limits of the systems to be studied.

Here are some examples:

- For ethanol production, the straw of the raw material (grain) is used as animal feed and replaces the production of hay. Thus, if this raw material is not cultivated for ethanol production, the straw should be substituted for hay. It also considers the raw material demand for ethanol production as additional to the existing demand. If ethanol is not produced, this land would not be cultivated.
- In the case of biodiesel, crude and used vegetable oils are transesterified to be used in vehicles [4]. This process generates glycerine

Table 1
Otto cycle systems to be studied.

System	Description
A1	E85: 85% ethanol (from cereals) and 15% unleaded gasoline 95
A2	E5: 5% ethanol (from cereals) and 95% unleaded gasoline 95
B	Unleaded gasoline 95

Table 2
Diesel cycle systems to be studied.

System	Description
BD5A1	Biodiesel from raw vegetable oil (95%) and gas–oil (5%)
BD10A1	Biodiesel from raw vegetable oil (90%) and gas–oil (10%)
BD100A1	Biodiesel (from raw vegetable oil)
BD5A2	Biodiesel from used vegetable oil (95%) and gas–oil (5%)
BD10A2	Biodiesel from used vegetable oil (90%) and gas–oil (10%)
BD100A2	Biodiesel (from used vegetable oil)
Gas–oil (Diesel EN-590)	Gas–oil (Diesel EN-590) from oil

Table 3
Systems so be compared for Otto cycle engine fuels.

System	Description
A1 vs. B	E85 vs. unleaded gasoline 95
A2 vs. B	E5 vs. unleaded gasoline 95

(a by-product) and it is considered that it replaces glycerine from fossil fuels.
- Moreover, the reference system for biodiesel from used vegetable oils includes the activities to recycle residual oil used as raw material because these activities would still occur if this used oil is not used for biodiesel production.

2.3.2. Otto cycle engines

Table 1 shows the systems to be studied.

2.3.3. Diesel cycle engines

Table 2 shows the systems to be studied.

2.4. Functional unit definition

The "Functional unit" is a unit of measurement used to evaluate the inputs and outputs of a system. CIEMAT chose the quantity of fuel (MJ) required to drive for a distance of one kilometre in a "typical" vehicle. This "typical" vehicle should be able to use biofuels and fossil fuels in order to compare them according to the test described in the European Commission directive 98/69/CE, thus:

- The *Ford Focus 1.6i 16 V Zetec Flexifuel* was elected to compare biofuels and fossil fuels for Otto cycle engines.
- The *Ford Focus 1.8 Tddi 90CV* was elected to compare biofuels and fossil fuels for Diesel cycle engines.

2.5. Systems' definitions to be compared

Table 3 shows the systems to be compared for biofuels and fossil fuels for Otto cycle engines.

Table 4 shows the systems to be compared for biofuels and fossil fuels for Diesel cycle engines.

2.6. Systems' limits identification

The limits of the systems determine which processes are to be included in the LCA The environmental impact of these processes is to be considered.

Table 4
Systems so be compared for Diesel cycle engine fuels.

System	Description
BD5A1 vs. Diesel EN-590	Biodiesel from raw vegetable oil (95%) and gas–oil (5%) vs. gas–oil
BD10A1 vs. Diesel EN-590	Biodiesel from raw vegetable oil (90%) and gas–oil (10%) vs. gas–oil
BD100A1 vs. Diesel EN-590	Biodiesel (from raw vegetable oil) vs. gas–oil
BD5A2 vs. Diesel EN-590	Biodiesel from used vegetable oil (95%) and gas–oil (5%) vs. gas–oil
BD10A2 vs. Diesel EN-590	Biodiesel from used vegetable oil (90%) and gas–oil (10%) vs. gas–oil
BD100A2 vs. Diesel EN-590	Biodiesel from used vegetable oil vs. gas–oil

2.6.1. Geographic limitations

The LCA for biofuels and fossil fuels are made for Spain. It does not mean that all stages of the LCA are restricted to Spain. For instance, LCA for fossil fuels includes the processes of extraction and transportation of crude oil that is produced outside Spain. The life cycles of ethanol and biodiesel production include raw materials and transportation to Spain if it is imported.

2.6.2. Time limitations

The LCA's time scope for biofuels and fossil fuels for Otto cycle engines is 2005 and for Diesel cycle engines is 2006.

2.6.3. Activities and processes excluded

The following environmental impacts are excluded due to their negligible value:

- Environmental impacts related to machinery production and all the infrastructures required to extract, transport and process crude oil. Its global contribution is lower than 1% [5,6].
- Environmental impacts related to agricultural machinery production, transport vehicles and the required processes to build the factories where biofuels are produced from raw materials.

It is important to note that the manufacturing processes of agricultural machinery may have a more significant impact [6,7], but are excluded in order to be consistent with the oil manufacturing processes.

The construction processes of the "typical" vehicles used to measures the fuel consumption of biofuels and fossil fuels are excluded from the analysis because the same vehicle is used for the fuels to be compared.

2.7. Comparison of results

2.7.1. LCA results for biofuels and fuels for Otto cycle engines

2.7.1.1. Energy balances. The higher ethanol mixture content, the better the energy balance (less primary and fossil energy is required) and vice versa. Results are shown in Table 5.

2.7.2. CO_2 and greenhouse gas (GHG) emissions

The higher ethanol mixture content, the lower CO_2 and GHG emissions and vice versa. Results are show in Table 6.

Table 5
Primary and fossil energy savings for biofuels mixtures for Otto cycle engines in comparison with unleaded gasoline 95.

Mixture	Energy savings in comparison with unleaded gasoline 95	
	Primary energy	Fossil energy
E85	17%	36%
E5	0.28%	1.12%

Table 6
CO_2 and GHG emission savings for Otto cycle engine biofuels and fossil fuels in comparison with unleaded gasoline 95.

Mixture	Emission savings in comparison with gasoline 95	
	CO_2 emission savings per km (g)	GHG emission savings per km (g of CO_2 equivalent)
E85	170 g (90% savings)	144 g (70% savings)
E5	8 g (4% savings)	7 g (7% savings)

Table 7
Primary energy saving for biofuels mixtures for Diesel cycle engines in comparison with gas–oil (diesel EN-590).

Mixture	Primary energy saving in comparison with gas-oil (Diesel EN-590) %
BD100A1	45
BD100A2	75
BD10A1	4
BD10A2	7
BD5A1	2
BD5A2	3

Table 8
CO_2 and GHG emissions savings for Diesel cycle engine biofuels and fossil fuels in comparison with gas–oil (Diesel EN-590).

Mixture	CO_2 emissions savings per km in comparison with gas–oil (Diesel EN-590)	
	g	%
BD100A1	120	91
BD100A2	144	84
BD10A1	12	8
BD10A2	15	9
BD5A1	6	4
BD5A2	8	5

2.7.3. LCA results for biofuels and fuels for Diesel cycle engines

2.7.3.1. Energy balances. The higher biodiesel mixture content, the better the energy balance (less primary energy is required) and vice versa. Results are shown in Table 7. This is especially significant for biodiesel whose raw material is used vegetable oil.

2.7.3.2. CO_2 and GHG emissions. The higher biodiesel mixture content, the lower CO_2 and GHG emissions and vice versa. Results are shown in Table 8. As for the energy balance, this is especially significant for biodiesel whose raw material is used vegetable oil.

2.8. CIEMAT's LCA's critical analysis published by AOP and Deloitte

The oil industry organisation, Asociación de Operadores de Productos Petrolíferos (AOP), in cooperation with he consulting company Deloitte, published in 2007 a study related to the requirements for the market penetration of biofuels in the automotive fuel market [8] which criticised the CIEMAT studies for the following reasons:

- CIEMAT concludes biofuels are always better than fossil fuels and considers that glycerine (a by-product of biodiesel production) will be a substitute product for synthetic glycerine. This is not true because in Europe synthetic glycerine is not used. Thus, to deduct the energy to produce glycerine in the energy balance and to deduct the CO_2 emissions in the same way in the mass balance is not correct.
- CIEMAT estimates that the distribution distance for gas–oil is 250 km using a tanker and for biodiesel only 64 km. There is no solid basis for this criterion. Distribution distances should be equal for both fuels.
- CIEMAT maintains that E85 allows a GHG emission reduction of up to 70%. Some other analyses, International Energy Agency (IEA) or US Department of Energy (USDOE.), estimate an average reduction of only 30%. The reason for this may be that electric energy via co-generation for ethanol production is considered while for gasoline production it is not. This criterion is not homogeneous.
- The European Commission analysis concludes that in order to obtain an energy unit of ethanol between 1.83 and 1.72 units of primary energy are required. CIEMAT concludes that to obtain an energy unit of ethanol less than a unit of primary energy is required. This means that ethanol production "creates" energy. This is impossible and it is a result of the cogeneration criterion.
- CIEMAT only considers a specific vehicle when evaluating the fuel consumption. This is not enough to draw conclusions. Besides, it seems quite strange to obtain a 10% consumption improvement when using ethanol instead of gasoline.
- CIEMAT estimates an average distance of 410 km using a tanker for distributing ethanol and gasoline. 80% of gasoline distribution is made using pipelines. This distribution method does not emit CO_2. These pipelines cannot be used for ethanol distribution.

2.9. CIEMAT's LCA's authors critical analysis

From the authors' point of view there is a critical error related to the functional unit definition. The chosen functional unit (fuel consumption of a particular vehicle) is not objective at all because a multifuel engine may be optimised for a particular fuel, being more efficient when using this fuel rather than using another one.

The best way to approach this problem is to compare the energy contained in the fuel by considering the Lower Heating Value (LHV). This is the adequate unit to compare different fuels. For instance, to compare fuel prices the best way is to compare the price per unit ofLHV at the petrol station. This means that the comparison of volumes should not be done because densities are different for different fuels. Hence, when comparing biofuels to fossil fuels:

- For Otto cycle engines, one volume unit of unleaded gasoline 95 is equal to 1.405 volume units of E85.
- For Diesel cycle engines, one volume unit of gas–oil is equal to 1.112 volume units of biodiesel.

Regarding CO_2 and GHG emissions, CIEMAT considers that for biofuels, all the CO_2 fixed by the raw material (vegetables fix CO_2 when growing due to photosynthesis) should be considered as a reduction of CO_2 emissions in the mass balance. However, this reduction should not always be considered because it depends on the origin of the raw material. Here are some examples:

- If wasteland or a desert is used for growing raw material for biofuel production, the CO_2 fixed by this raw material should be considered in the mass balance as CIEMAT does.
- If an area is deforested to cultivate raw material for biofuel production, the CO_2 fixed by this raw material should be considered in the mass balance but also the CO_2 fixed by the vegetables that previously existed should be also taken into account in the mass balance.
- If vegetable waste is used as raw material for biofuel production, the CO_2 fixed by this raw material should not be considered in the mass balance. This is because this raw material is a by-product, not a product itself. The purpose of this cultivation is not to produce biofuel but to produce the vegetable itself.

On the other hand, it is apparently not very rigorous that personnel of the vehicle manufacturer used as functional unit and personnel of companies that produce biofuels were engaged in the review of the CIEMAT studies.

3. LCA – The origin of the controversy

The identification of the system boundaries and the election of the functional unit are the origin of the controversy related to the mass and energy balances.

The use of corn as raw material to produce ethanol [9] is a good example for this because the following issues are involved in the discussion:

- If the required energy to feed the corn farmers should be included or not.
- If the required energy to build and maintain the farm fences should be included or not.
- The quantification of the energy consumption of agricultural machinery.

Even more, there is not a common criterion to estimate the value of the residues of the plant once the corn is harvested, (for instance, the straw). Some studies consider leaving it in the field to protect the soil and some other would prefer burning it and using this heat as a primary energy source for the ethanol production plant. The second option should consider that more fertilizer is required to avoid soil erosion.

Depending on the study, net energy for ethanol production goes from 0.7 to 1.5. This means that the use of one unit of fossil energy produces between 0.7 and 1.5 units of energy of ethanol (measured on the LHV).

In comparison with this, the use of one unit of fossil fuel to extract and process oil to obtain gasoline produces 15 units of energy of gasoline (measured on the LHV.) but this comparison is not properly well done because oil is not a renewable resource as ethanol is.

In order to minimise the problem caused by the identification of the system limits (this problem will always exist), a new evaluation model is proposed. This new model incorporates an economic approach to the LCA's comparison as is described in the following section.

4. The new LCA model

4.1. Introduction

The new LCA model developed by authors is based on the optimisation of the factors of production, taking into consideration the maximisation of the economic profit and the sustainable use of resources.

In economics, factors of production (or productive inputs or resources) are any materials or services used to produce other goods and services. In this particular case, 'Factors of production' refer specifically to the primary factors, which are stocks including land, labour and capital goods applied to production [10].

To get the best combination of the factors of production is the way for a country to achieve its objectives. This combination or mix varies over time and depends on many circumstances such as the need for growth, availability of skilled labour, the experience of managers, the availability of new technologies or the contributions of products and services.

4.2. Factors of production

4.2.1. Land as a factor of production

Land or natural resources are naturally-occurring goods such as water, air, soil, minerals, flora and fauna that are used in the generation of products. The payment for land use and the income received by a landowner constitutes rent.

4.2.2. Labour as a factor of production

Labour refers to human effort used in production which also includes technical and marketing expertise [11]. The payment for someone else's labour and all income received from one's own labour constitutes wages. Labour can also be classified as the physical and mental contribution of workers to the production of goods.

4.2.3. Capital as a factor of production

The capital stock refers to human-made goods (or means of production) which are used in the production of other goods. These include machinery, tools and buildings.

4.3. New model philosophy

The new model philosophy is the optimisation of the use of the factors of production of a country, that is, finding those activities or processes that optimise the economic value of the production factors of a country. This new model also assesses the impact of the different activities on the environment, paying special attention to CO_2 and other GHG emissions.

4.4. Model description

In contrast to the conventional LCA model, the new model assesses the potential applications for a given factor of production according to its technical and economic evaluations and the environmental impact.

The phases of this new model are:

1. Identification of the factor of production to be assessed.
2. Identification of the potential applications of this factor of production.
3. Identification of the existing products in the market with which the potential applications of the factor of production may compete.
4. LCA's for the potential applications of the factor of production and the products with which these potential applications would compete. These LCA's would be similar to the conventional LCA's: Objectives definition, election of the systems to be studied, functional unit definition, etc. The aim is to get the mass and energy balances that allow the assessment of the energy efficiency of the factor of production and its environmental impact (GHG emissions and the consumption of pollution products).
5. Economic evaluation of potential applications of the factor of production. At this point, the most common financial evaluation methods such as Net Present Value (NPV), Internal Rate of Return (IRR) or Profitability Index (PI) can be used. When calculating these values, government subsidies and tax exemptions must be taken into account.
6. Identification of the best application of each factor of production. The economic analysis is required to know the profitability of the potential applications while the LCA's determine the environmental impact of the potential applications in comparison with the alternative products that already exist in the market. The election of the most convenient application might be performed by a multidisciplinary team.

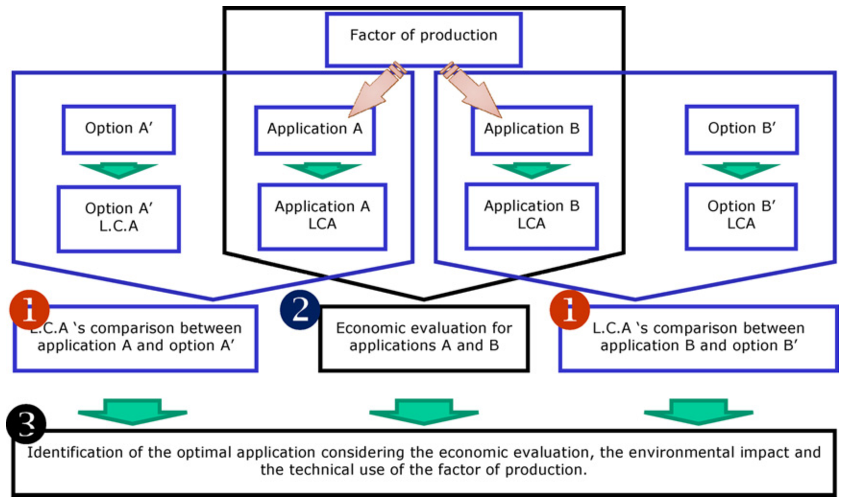

Fig. 1. New LCA evaluation model for the potential applications of a factor of production.

This model is shown in Fig. 1 where:

- Number 1 identifies the LCA's comparisons between the potential applications for the factor of production with the alternative products that already exist in the market.
- Number 2 identifies the economic analysis of the potential applications for the factor of production.
- Number 3 identifies the activity selecting the best potential application for the factor of production that takes into account the LCA's comparisons and the economic analysis.

5. New LCA case study

5.1. Description

In 2003, the European Directive 2003/30/CE was issued in order to regulate the use of biofuels in the automotive fuel market. Being a compulsory directive for all EU members, individual EU governments are encouraging actions to comply with it.

In a previous report [12], authors made a critical analysis of this initiative in order to find out if the obligation imposed by this directive applies to achieve uniform and/or identical goals in each of the countries involved and whether the actions of the various governments are also aligned with these goals. A technical and economic study was performed to compare two different applications of citrus fruit waste produced in the Comunidad Valenciana: the construction and exploitation of an ethanol production plant and the construction and operation of two thermal power stations. The study was made based on the following assumptions:

- Ethanol produced at the production plant would replace an equivalent amount of gasoline 95 in energy terms and would be used as an automotive fuel.
- Electricity generated by thermal power plants would replace an equivalent amount of electricity produced in a gas or fuel oil power plant.
- The required energy and CO_2 emissions for citrus cultivations would not be taken into account, except for the energy and the CO_2 emissions coming from the transportation of citrus waste to the ethanol production plant and to the power plants.

Citrus waste may be considered as a land factor of production and it is generated as a by-product of the citrus harvest. This factor of production may have, at least, the following uses:

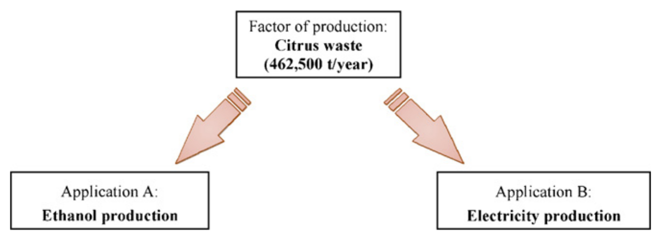

Fig. 2. Factor of production to be optimised: citrus waste and its potential applications.

1. Ethanol production in a new factory.
2. Power generation in two new power plants.
3. Animal feed.
4. Chemicals for pharmaceutical products and cosmetics

For this case study, only the first two applications are to be evaluated. This is shown in Fig. 2.

Once the potential application of the factor of production has been identified, it is possible to proceed with the next step: to identify the products that already exist in the market that compete with these potential application of the factor of production: Gasoline 95 (for ethanol production) and coal, gas and fuel–oil power plants (for electricity production).

Knowing the products that compete with the potential application of the factor of production, the identification of the functional unit and the system boundaries definition can be done. These are the previous activities required to perform the LCA's for potential applications and competitive products.

At this point, it is possible to proceed with the comparisons:

1. Economic comparison is to be carried out for the different potential applications of citrus waste (ethanol production vs. power generation). The most important economic indicators for both applications should be calculated: NPV, IRR, IP, etc. For the ethanol production case, public aid (in this case it is a tax exemption) should be taken into account because the Spanish Government would collect this tax if gasoline is used instead of ethanol.
2. LCA comparisons are to be carried out for the different potential applications of the citrus waste and their alternative products that already exist in the market.

a. Ethanol production is compared to gasoline 95 production.

Table 9
Mass and energy balance comparison of the potential applications of the citrus waste.

	Ethanol processing plant	Power plants
Annual production	37,000,000 l of ethanol	677 GWh
Electric energy required (per year)	13.38 GWh/year	0 GWh/year
Heat required (per year)	19.00 GWh/year	0 GWh/year
CO_2 emissions	36–140% increase	19–54% increase
Annual energy savings	18.43 million Ktoe	233.74 million Ktoe

Table 10
Most significant metrics of the potential applications of citrus waste.

	Ethanol processing plant	Power plants
N.P.V.	35.79 million €	169 million €
Profitability	89	85
I.R.R.	11	13
Breakeven (year)	10th	10th

b. Power generation is compared to coal, gas and fuel oil power generation.

Finally, identification of the best application for the factor of production (citrus waste) can be done. The decision should be undertaken by a multidisciplinary team in reaching a consensus. Fig. 3 shows the new LCA model for the citrus waste case study.

5.2. Results

5.2.1. Mass and energy balances

Table 9 shows the most relevant data related to the mass and energy balance comparisons for citrus waste applications. The CO_2 absorbed by the raw material (the citrus plants) has not been taken into account because the raw material is a residue and the main purpose of cultivating citrus is to obtain the fruits, not to obtain their waste.

5.2.2. Economic evaluation

The economic evaluation has been performed using the following assumptions:

- 462,500 tons per year of citrus waste are produced in Comunidad Valenciana.
- An ethanol production plant may produce 80 l of product per ton of citrus waste.
- To produce electric energy using the annual production of citrus waste requires building two 50 MW power plants.
- The weighted average cost of capital (WACC) is 5% for both projects.
- Building the ethanol production plant and the two 50 MW power plants requires two years.
- The expected lifetime for the ethanol production plant and for the power plants is 19 years.

The most significant indicator meters of the potential applications of the citrus waste are shown in Table 10.

It should be noted that 37 million litres of ethanol in the market reduce the consumption of gasoline 95 by an amount of 13.74 million litres. Ethanol is not charged with the hydrocarbons special tax. Hence, an amount of 10.94 million Euros per year are not collected by the tax authorities. The Net Present Value of this tax reduction is 125.81 million Euros and should be taken into account. Thus, Table 11 shows the corrected results.

Table 11
Most significant indicator meters of the potential applications of the citrus waste (corrected).

	Ethanol processing plant	Power plants
N.P.V.	35.79–125.81 = −90,02 million €	169 million €
Profitability	–	85
I.R.R.	–	13
Breakeven (year)	–	10th

5.2.3. Decision making

At this point it is time to decide which application is better. Authors maintain that to produce electricity is better than to produce ethanol because the first option allows saving more oil than the second one and from the economic point of view it is more profitable.

Obviously, this is only an example. In a real case all the potential applications for citrus waste should be taken into account.

As it has been previously commented, the European Union directive 2003/30/EC [1] was enacted with the sole aim of promoting the use of biofuels as a substitute for diesel or gasoline and to reach the following objectives:

- The fulfilment of the commitments to climate change. That is, reducing the emissions of carbon dioxide and thus complying with the Kyoto Protocol.
- The security of supply under environmentally friendly conditions, that is, finding energy sources to avoid absolute dependence from foreign sources.
- The promotion of renewable energy sources, i.e., finding alternative energy sources that are less harmful to the environment.

In order to achieve these goals, the directive requires all EU countries to consume a minimum of 5.75% of biofuels in all petrol and diesel fuel sold for transport purposes before 31 December 2010.

The commented previous report [12] is a critical analysis of this initiative that shows that the obligation imposed by this directive applies to achieve uniform and/or identical goals in each of the countries involved and that the actions of the various governments are not always aligned with these goals. The case study for the use of citrus waste in a newly built plant in L'Alcudia, Valencia (Spain) showed that this consistency is not always achieved.

Nowadays, due to state of the art technology and costs, forcing the production and consumption of biofuels is not cost-effective. This is because, from an economic point of view, it is very difficult for biofuels to compete with mineral fuels. Mineral fuels are extracted from geological formations, processed and delivered to consumers while biofuels require the processing of the raw materials which is both complex and expensive in terms of energy and economic cost.

In combustion terms, the amount of CO_2 generated by biofuels is similar to that of fossil fuels. Furthermore, the process of getting fuel from plants requires energy (heat and power) and in order to obtain this energy CO_2 is generated. Raw materials for biofuels have absorbed CO_2before it reaches the processing plant but this absorption should not always be taken into account in the mass and energy balances.

It is important to point out that in certain European countries like Spain (which has a strong primary sector), a high percentage of the raw materials used to produce biofuels is imported. This calls into question the objective of European Directive 2003/30/EC for the reduction of the external energy dependence because this dependence is replaced by the dependence on the raw materials to produce biofuels.

The authors made also a critical analysis of the use of hydrogen as an automotive fuel [13]. Hydrogen can be used in internal com-

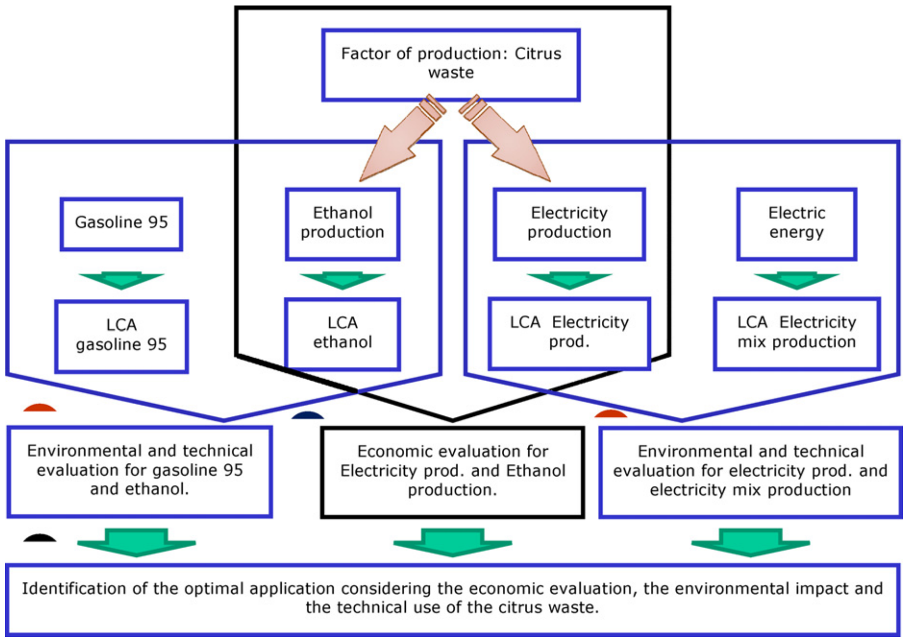

Fig. 3. New LCA evaluation model for the potential applications of citrus waste: ethanol production and electric power production.

bustion engines or in fuel cells. An analysis of a model to produce hydrogen via electrolysis of sea water was performed. The results of this analysis showed that, depending on the energy cost and the process efficiency, there is a wide range of possibilities in which the generation of hydrogen by electrolysis is cost-effective without requiring subsidies or tax exemptions [13].

6. Conclusions

Controversy arises when evaluating mass and energy balances for biofuels due to the system limits identification and the functional unit identification. In order to minimise this controversy a new model is proposed.

The new model proposed is based on the utilisation and maximisation of the factors of production. This new point of view provides an important element of comparison: the economic one that helps minimise the controversy of the system limit identification because the new model is not affected by this problem as mass and energy balances are.

The results of the case study (the evaluation of the potential applications of citrus waste) show that producing electricity is more convenient that producing ethanol. This is because producing electricity saves more oil and is more profitable from the economic point of view than to produce ethanol.

In Spain, it was decided to produce ethanol with citrus waste. Obviously the decision may have been motivated for some other reasons such as complying with the 2003/30/EC Directive related to the use of biofuels in the European Union.

In case the final reason was to find an alternative to fossil fuels, a better option may have been to produce hydrogen via electrolysis.

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